INTERNATIONAL DESIGN CONFERENCE – DESIGN 2024
https://doi.org/10.1017/pds.2024.289

Towards simulation games in engineering design education - design and evaluation of a SE simulation game

David Inkermann and Theresa Ammersdörfer ✉

Technische Universität Clausthal, Germany

✉ ammersdoerfer@imw.tu-clausthal.de

Abstract

Simulation games (SG) present a learning environment allowing 'what-if' analysis of solutions and decisions that may not be feasible in reality. Positive effects of SG are affected by the context of use, users, and the game design itself. Aim of our research is to investigate to which extent it is possible to represent interdependencies occurring between activities, methods, tools, and roles in real engineering projects by a SG and which prior knowledge is needed for the intended learning outcomes. Our research uses a SG prototype and interviews with industry experts and graduated students.

Keywords: gamification, engineering simulator, training, design education, systems engineering (SE)

1. Introduction

Driven by the increasing complexity of modern products as well as the required competencies to work in interdisciplinary teams, a core challenge of modern engineering education is to train students to collaboratively solve complex and poorly structured problems involving both technical and social aspects. Besides technical competencies and the underlying domain-specific knowledge, engineers have to manage complexity, work in interdisciplinary teams as well as understand and communicate interrelations from a systems perspective including both technical and user requirements (Crawley *et al.*, 2011). Learning settings based on a lecture-based format accompanied by rigorous problem-solving exercises are limited to building up these skills (Baillie and Fitzgerald, 2000). Thus, more often project-based learning settings are used in engineering education. Here students have to handle problems defined beforehand and apply different methods and tools (Wang *et al.*, 2017). Gamification and in particular Simulation Games (SG) enable to setting up of learning environments that allow for *'what-if'* analyses on a number of different strategies and solutions, which may not be feasible in reality (Deshpande and Huang, 2011). By accounting for their success and mistakes in a simulated environment, students are motivated to accept personal responsibility for their own decisions. SG-based learning can be understood as an extension of the problem-based learning paradigm (Deshpande and Huang, 2011), engaging learners in understanding complex concepts and providing holistic working knowledge (Kharma *et al.*, 2001). The positive effects of SG are affected by the context in which gamification is used, the users using it, and the design of the SG itself (Hamari *et al.*, 2014). Therefore, a core challenge is to build up a simulation model representing the learning content like physical laws or phenomenon of process design and method application in a realistic manner and at the same time allow a game dynamic to ensure the attractiveness of the game and motivation of learners. In this paper, we report the design and initial evaluation of a SG to educate and train Systems Engineering (SE) including basic processes, methods, tools, and roles proposed for successful SE-projects in different literatures. Our objectives are (a) to *investigate how and to which extent it is possible to represent the manifold interdependencies* *occurring in real-world engineering projects by a simulation model and thus use it for gamification* and (b) to *identify which previous knowledge is required to ensure the defined learning outcomes*. The underlying questions are answered based on a prototype of a SG and interviews with experts from industrial practice and graduated students from the university involved in a workshop.

1.1. Concepts and benefits of gamification in engineering education

In the last decade, the use of games as educational tools has gained increased interest in many fields of engineering (Deshpande and Huang, 2011) including mechanical engineering. A variety of games can be found in literature, including computer SG using animations, graphics, and an interactive environment e.g. for gear design and analysis based on adapted video games (Chang et al., 2016), simulations to represent challenges when setting up companies in competing markets (Braghirolli et al., 2016), simulations to teach the impact of design and production decisions on ecology, economy, and society, a Resin Puzzle game to undertake a variety of engineering design activities and design tasks using CAD/CAM technologies (Mavromihales et al., 2019), and games focussing on specific methods and development approaches like SCRUM (Fernandes and Sousa, 2010) or Design Thinking (Bhatt and Chakrabarti, 2022). While these games incorporate different game elements and didactics, c.f. Section 2.1, addresses a wide range of learning contents, there is a common ground of the benefits and effects associated with gamification. Various empirical studies show that gamification has a positive effect on learners' interest, early engagement (Betts et al., 2013), and learning outcomes, e.g. retention rate (Vaibhav and Gupta, 2014). Based on a literature review, Deshpande and Huang (2011) determine the essential advantages of gamification in general and SG in particular. Thus, SG *helps to connect theory and practice to foster learners' understanding of the subject, give immediate feedback to the learners, and provide learners the opportunity to face the consequences of decisions taken and processes applied* and *have an increasing range of difficulty to challenge the learners to develop to a more advanced level of comprehension.* Braghirolli et al. (2016) assess the usefulness of education games from the learner's perspective using three criteria, namely *improvement of the individual learning performance, facilitation of learning about complex situations and opportunity to experience realistic situations*, and *the belief that education games are helping in learning.* Hartmann and Gommer (2021) focus on the motivational character of education games in engineering and point out the co-existence of self-determined and non-self-determined forms of motivation. They define *game operativeness* (game structure and goal, time for playing, number of players, and functioning of the game) *game attractiveness* (challenge of the game content, engagement through interaction, competition between teams, and direct feedback), and *game learning* as main aspects to be considered. They found that the combination of interaction and competition has a strong motivational effect on learners to engage and continue with the game. This effect is increasing when giving direct feedback on the team's performance.

1.2. Research objective and methodology

Our research is placed in the context of designing and applying SG in engineering design education focussing on the processes, methods, tools, and roles in the field of SE. The main objective of this paper is to investigate how a simulation model can be built up to teach the manifold interactions that are observed in practice as well as the impacts associated with particular processes, methods, tools, and roles when setting up engineering projects following the principles of SE (Inkermann, 2021). Since research on education games has pointed out the influence of the game design (game operativeness and attractiveness) on the learning outcomes, the focus is on the evaluation of the simulation model used in a game prototype as well as the game mechanics. In addition, we investigate the previous knowledge needed to achieve the intended learning outcomes. Our research is based on a mixed method approach to gain qualitative and quantitative insights for the design of a SG for SE. The further content of this paper is organized as follows. In Section 2, we refine the understanding and elements of SG in engineering education and introduce existing frameworks to classify, develop, and evaluate education games. In Section 3, we specify the purpose and design of the SG called Systemic developed by the chair of Integrated Product Engineering at TU Clausthal and explain the development of the simulation model used in this game. In Section 4, we present the results of an initial evaluation, including the

https://doi.org/10.1017/pds.2024.289 Published online by Cambridge University Press

assessment of the simulation model by experts from the field of SE and a review of the previous knowledge needed by learners to perform in the SG and achieve the intended learning outcomes.

2. Characteristics and development of simulation games

Gamification in general refers to the use of elements of games and applying them to existing learning courses to fulfil learning objectives (Deterding *et al.*, 2011). When designing games for educational purposes, it is essential to know about the approaches available. Bhatt and Chakrabarti (2022) differ between gamification, serious games, and SG. In this publication, the focus is on SG aiming to represent processes or phenomena observed in reality within an education game. Therefore, a mathematical or algorithmic model with an appropriate set of constraints is used to allow a predictive analysis of the system (Deshpande and Huang, 2011) and enables learners to experience the consequences of their decisions with no or fewer costs of error. By adding game elements like fantasy, rules, challenges, or winning conditions to this simulation, it becomes a SG (Crooltall *et al.*, 1987). Thus, SG follow a *practice in safety* approach to implement the optimal decisions with the required constraints. In the following Subsections, we explain existing taxonomies supporting the development and evaluation of SG and introduce relevant elements and steps to be considered when developing SG.

2.1. Taxonomies for game development and evaluation

To aid researchers, educators, and developers in understanding, developing, and evaluating educational games different taxonomies are reported in the literature. These taxonomies are used to analyse existing games and drive development as well as evaluation of new games. Based on the analysis of existing taxonomies Bhatt *et al.* (2021) propose an extended taxonomy defining nine aspects. The taxonomy covers the area of application and purpose (*target group, time, objective, player mode, and innovation phase*), the game's concept and implementation (*game approach, platform*), and the levels of evaluation addressed. Since the work of Bhatt *et al.* (2021) focuses on gamification in the field of innovation and design, the innovation phase is considered as a specific aspect. In Figure 1, the different aspects of the taxonomy are presented, and three existing games are classified according to the given criteria. In addition, the SG developed in this research, c.f. Section 3, is characterized according to this taxonomy.

	Game Approach			Platform			Target Group			Time		Objective			Player Mode			Innovation Phase				Evaluation Level			
Educational Game	Gamification	Serious Game	Simulation Game	Digital	Analog (plan)	Hybrid	Pupils	Students	Professionals	During training	After training	Multiplication	Knowledge transfer	Training	Single player	Multiplayer	Subteams	Development	Realization	Service	Operation	Reaction	Learning	Behavior	Results
Holistic (Herrmann et al., 2011)			■		■	■		■			■	■		■			■			■	■		■	■	
Dbox (Bhatt et al., 2019)	■				■		■			■			■	■		■		■				■	■		■
Lino (Libe et al., 2020)		■			■		■			■			■	■		■		■				■			■
Systemic			■		■	■		■	■		■		■	■		■	■	■	■				■	■	

Figure 1. Taxonomy for the classification and development of innovation and development learning games according to Bhatt *et al.* (2021) and exemplary games according to Herrmann et al. (2011), Bhatt *et al.* (2019) and Libe et al.(2020)

While the taxonomies and frameworks proposed in the literature serve to classify and analyse existing games and position new ones, the development requires a more detailed understanding of the elements to be used to realize effective games for learning settings. In the following Subsection, basic elements and a procedure for the development of educational games are introduced.

https://doi.org/10.1017/pds.2024.289 Published online by Cambridge University Press

2.2. Game elements and development

To use the positive effects of gamification, the following preconditions have to be fulfilled (Bhatt and Chakrabarti, 2022): (a) *the learning objectives and outcomes have to be well defined*; and (b) *efforts have to be spent to assess the effect of gamification on those learning outcomes*. To handle these preconditions different frameworks and approaches for the development are proposed in the literature, including the Serious Game Design Assessment (SGDA) (Mitgutsch and Alvarado, 2012), the Innovation Serious Games Design (ISGD) (Ma *et al.*, 2020), the Mechanics, dynamics, and aesthetics (MDA) framework (Hunicke *et al.* 2004), and general procedures, c.f. (Bhatt and Chakrabarti, 2022). While these frameworks and approaches guide the development process and enable the classification of existing games, c.f. Section 2.1, there are several game elements to be considered within the development. These game design elements can be classified into five levels (Deterding *et al.*, 2011), c.f. Table 1, and can be understood as a set of building blocks or features shared by games (rather than a set of necessary conditions for a game).

Table 1. Levels of game design elements, following (Deterding *et al.*, 2011)

Level	Description	Example
Game interface design patterns	Common, successful interaction designs and design solutions for a known problem in a context, including prototypical implementations	Badge; leader board; game level
Game design patterns and mechanics	Commonly reoccurring parts of the design of a game that concern gameplay	Time constraints; limited resources; turns
Game design principles and heuristics	Evaluative guidelines to approach a design problem or analyse a given design solution	Enduring play; clear goals; variety of game styles
Game models	Conceptual models of the components of games or game experience	Mechanics, dynamics, and aesthetics; challenge; fantasy; curiosity; game design atoms
Game design methods	Game design-specific practices and processes	Playtesting; play-centric design; value-conscious game design

While these elements apply to all kinds of educational games, Deshpande and Huang (2011) introduce a specific classification to address the different types of SG. Thus, *drill-based* SG serve for observing a particular phenomenon. *Exercise-based* games require learners to choose correct techniques or strategies to solve a given problem, while *problem-based* games allow trying several approaches depending on the assumption made. In *mini-case* SG, learners are facing a scenario with a suitable description and are asked to come up with a solution satisfying the constraints given in the simulation. To realize the different types of SG, appropriate game elements are needed. This results in a structured process for the development of SG starting from the definition of the learning subject and intended learning outcomes, c.f. Figure 2.

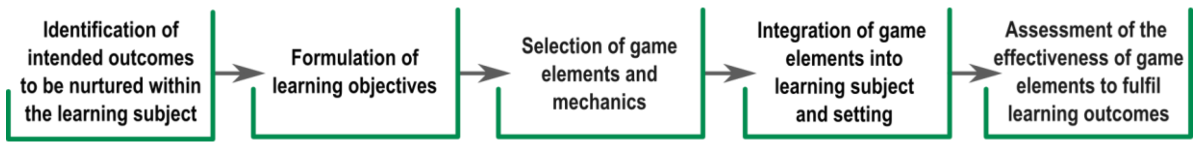

Figure 2. Activities for structured development and evaluation of gamification in the context of engineering, adapted from Bhatt and Chakrabarti (2022)

The fundamentals of game development and evaluation introduced in this Section were used to design a SG to train students and professionals in implementing measures to realize engineering projects following the principles of SE. Basic characteristics of this SG are given in Figure 2. Referring to the classification of Deshpande and Huang (2011), the realized game is a mini-case SG. The structure and elements of the SG Systemic are described in the following Section.

https://doi.org/10.1017/pds.2024.289 Published online by Cambridge University Press

3. Structure and simulation model of the simulation game systemic

Shaping the socio-technical systems of engineering organizations is a challenging task caused by the manifold objectives and measures to be considered (Ammersdörfer *et al.*, 2023). At the same time, there is an increasing need to adapt methods and tools following the principles of SE (Inkermann, 2021) to cope with the increasing complexity of engineering projects and systems. To structure the core fields of action to implement SE, Martin (1994) introduces the PMTE paradigm. This point out the relationships between processes (P), methods (M), tools (T), and environment (E). A core challenge in education and training is to teach the manifold interactions and different strategies when adapting processes, methods, tools, and the organization. To tackle this challenge a SG, called Systemic, has been developed at the chair for Integrated Product Engineering at TU Clausthal.

3.1. Purpose and elements of the simulation game systemic

Systemic has been designed following the systematic procedure introduced in Section 2. It is based on an analogue (game plan, action cards) and hybrid (simulation model) platform and aims to teach awareness for the implementation of processes, methods, tools, and roles of SE to students and professionals, c.f. Figure 1. Therefore, a multiplayer mode including four sub-teams is realized to transfer knowledge about specific processes, methods, tools, and roles and train their suitable application in a given scenario. In Table 2 purpose, content, and information as well as mechanics are summarized. Within the SG, an engineering organization (*Big Mountains AG*) is represented. This company is structured into four departments representing the essential activities of SE, namely:

- ***System Definition and Design,*** including stakeholder needs and requirements analysis; requirement management; architecture design and evaluation; subsystem and module specification,
- ***Subsystem Development and Implementation,*** including analysis and simulation; engineering and implementation; technology management,
- ***System Integration and Validation,*** including system integration; subsystem and system verification; subsystems and system validation; system launch and maintenance, and
- ***Project Management,*** including project planning and control; information management and communication; decision and risk management; configuration and change management.

For each department, there is a physical game plan (c.f. Figure 4), introducing different measures for the implementation of SE. The four departments are assigned to four sub-teams taking the responsibility to select the action cards, c.f. Subsection 3.3, and thus contribute to the strategy of the overall company. The goal of the game is to define a strategy for the implementation of SE and implement suitable processes, methods, tools, and roles (environment). To represent the effects of the different measures represented by 86 action cards a simulation model is used, c.f. Subsection 3.2.

Table 2. Design elements of the simulation game systemic

Design Elements	Short Description of Systemic
Game purpose	Impart connections between processes, methods, tools, and roles and recognize preconditions for the implementation of SE in engineering organizations.
Game content and information	Basic information about processes, methods, tools, and roles based on ISO 15288, INCOSE Systems Engineering Handbook and further literature form engineering design. Validated interactions between and preconditions for the implementation of processes, methods, tools, and roles in engineering organizations based on literature.
Game mechanics	Physical game plan and action cards; simulation model including rules (preconditions) and impacts on key performance indicators to represent the effects of single action cards (measures) when implementing SE; limited resources in a round-based procedure.

3.2. Simulation model used in the simulation game systemic

The core element of the SG is a simulation model to represent the effects of single measures on redefined key performance indicators (KPI) that represent the performance of the fictive engineering organization

https://doi.org/10.1017/pds.2024.289 Published online by Cambridge University Press

called *Big Mountains AG*. This simulation model is intended to represent the effectiveness of processes, methods, tools, and roles observed in reality as well as preconditions that must be met for these measures to be effective. In Figure 3, the main elements of the simulation model are illustrated. To assess the effectiveness of 86 measures (action cards), three KPI, namely c*ustomer satisfaction*, *development efficiency, and innovation capability* are used. At the same time, these KPI are used by the learners to define their specific strategy at the company level. To describe the effect of single measures on these KPI seven influencing factors are used c.f. Figure 3 left-hand side. For each action card, the impact of each influencing factor was rated on a scale from -5 to 5. Therefore, information about the effects of specific processes, methods, tools, and roles given in the literature was used. Aside from the quantitative impact of the single measures (action cards) on the influencing factors and thus KPI, the simulation model represents the preconditions that need to be fulfilled to make the measures work. These preconditions are represented by logical links, c.f. Figure 3 centre part. For instance, a process requires a specific method to be implemented or a role needs a tool to perform the assigned tasks. These preconditions are illustrated by an X and indicate that the impact of a specific action card is only given in case that the learners also implement the action cards defined by the preconditions. Taking the first example given in Figure 3 (centre part) for the *Structured life cycle analysis* to become active also a *Life cycle model* is required. The resulting impact on the KPI is used to give feedback on the learners' decisions within one round, c.f. Section 3.3. To enable the selection of single measures (action cards), each card provides basic information on its core idea as well as advantages and disadvantages, c.f. Figure 3, right-hand side. Moreover, the impacts on the KPI are illustrated to assist the team in deciding which action card to consider. The simulation model comprises 86 action cards and their impacts on the influencing factors and KPI as well as 126 preconditions and thus represent the complexity observed in real PMTE-systems of engineering organizations. The digital simulation model and the physical playing cards are linked via a barcode.

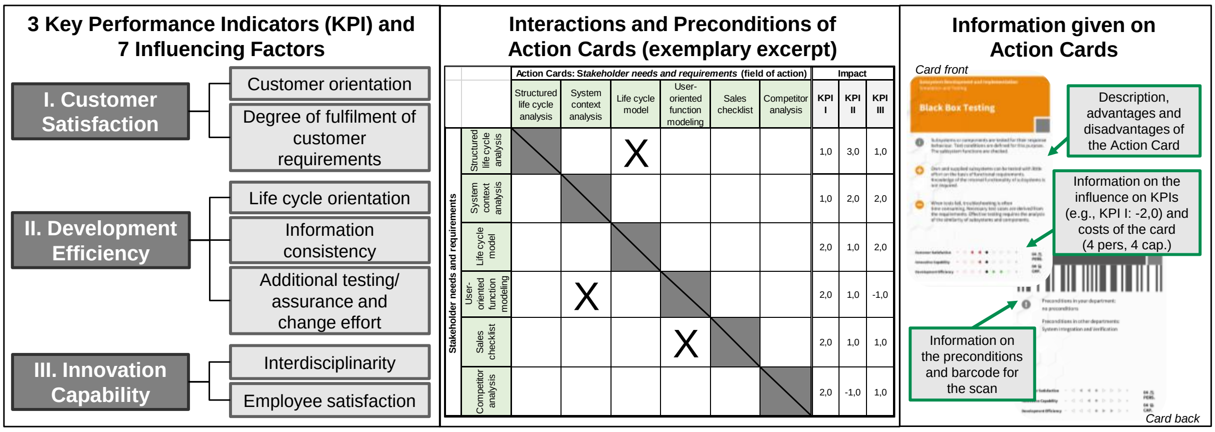

Figure 3. Key performance indicators and influencing factors used in the simulation model to represent the impact of single measures (left-hand side), interactions between measures (centre part), and information given to learners by the action cards (right-hand side)

3.3. Tasks and procedure of the simulation game

The game starts with a short introduction and the current situation of the fictive company *Big Mountains AG*. The briefing is done by a moderator and includes the definition of initial characteristics of the KPI. The learners are grouped into the four sub-teams and assigned to the departments. The overall game is structured into rounds, each comprising four phases, c.f. Figure 4. The *strategy phase* includes the allocation of resources (start scenario: 16 capital and 16 personnel for the whole company), strategic planning, objectives for the company (e.g., increasing customer satisfaction), and the definition of the content focus. In the *company phase*, the contents of the sub-teams' fields of action on the game plans are discussed and the company is informed about the focal points and measures that the sub-teams would like to address. In the third phase, *the department phase*, the sub-teams select their cards for each field of action, define the resources that are needed, and discuss and negotiate this across the teams. The capital and personnel tiles are distributed on the layout plan for each sub-team and finally logged into the system using a barcode scanner. In the *balancing phase*, the cards played are evaluated by the simulation model and visualized by a bar chart. The change in the three KPIs is displayed, and feedback is given as to which cards played became active or remained inactive. This feedback is given based on the results of the simulation model.

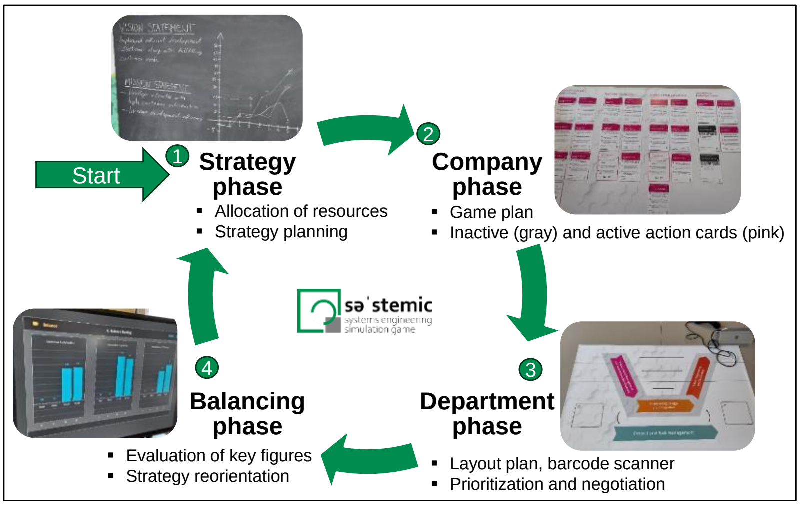

Figure 4. Procedure, phases, and tools used in the simulation game systemic

4. Evaluation of simulation model and learning setting

In a first stage of our research, the objective was to evaluate the simulation model and basic learning setting implemented by the prototype described in Section 3. Following Section 1, the guiding research question was *how and to which extent it is possible to represent the manifold interdependencies occurring in real world engineering projects by a simulation and thus use it for gamification* and *which previous knowledge is required to ensure the defined learning outcomes?* The evaluation was conducted in a workshop including an introduction into gamification, a gaming session covering 7 rounds of the SG Systemic and structured feedback, and evaluation using a questionnaire. Overall, 17 persons participated in the workshop. These persons were experts in the field of SE having several years of experience in practice as well as a smaller number of persons having almost no previous experience in SE. The SG was evaluated using the Serious Game Design Assessment Framework (Mitgutsch and Alvarado, 2012).

4.1. Evaluation of the simulation model

The basic objective of the SG Systemic is to provide a learning environment to train the impact of different measures for the improvement of processes, methods, tools, and roles following the principles of SE. Therefore, a simulation model is needed to represent impacts and preconditions in a realistic manner and at the same time allow a game dynamic. Therefore, the first SG evaluation relates to the simulation model. To evaluate the implemented simulation model, c.f. Subsection 3.2, persons from different companies familiar with the fundamentals of systems engineering. The background of the participants was captured using a questionnaire and a Likert scale (5 = fully applies, 1 = does not apply) to rate different statements. In Figure 5, left hand side presents the background of the participants using a box plot diagram. It can be concluded, that the participants have sound experience in SE and are thus qualified to evaluate the simulation model based on their practical experience. In particular, the responsibility to introduce new methods and tools is valuable to give feedback on the simulation model. The right hand side of Figure 5 refers to the coherence and cohesion of the game system. Following Mitgutsch and Alvarado (2012), this aspect refers to the interaction of the individual game elements to fulfil the purpose of the game as well as coherence and cohesion between narrative and game mechanics. To evaluate the simulation model five statements were assessed by the participants, c.f. Figure 5 right hand side. The participants rated the simulation model to be suitable to represent the problem area of

https://doi.org/10.1017/pds.2024.289 Published online by Cambridge University Press

the SG (arithmetic mean = 4.19). Moreover, the preconditions and influence of the single measures are evaluated to be predominantly realistic (arithmetic mean = 3.47). This is important to represent the interdependencies observed in reality majority. A differing understanding of single terms as well as divergent understandings of single processes and methods, both in literature and industrial practice, can explain the lower rating of the qualitative impact of single measures. Furthermore, there are differing experiences of single measures in industrial practice. Referring to the first research question, it can be concluded that the simulation model is suitable to represent the problem area of the SG sufficiently realistic and at the same time supports the game dynamic. To further improve the simulation model, single influencing factors of single measures must be reviewed and individual action cards should be revised concerning terms and descriptions.

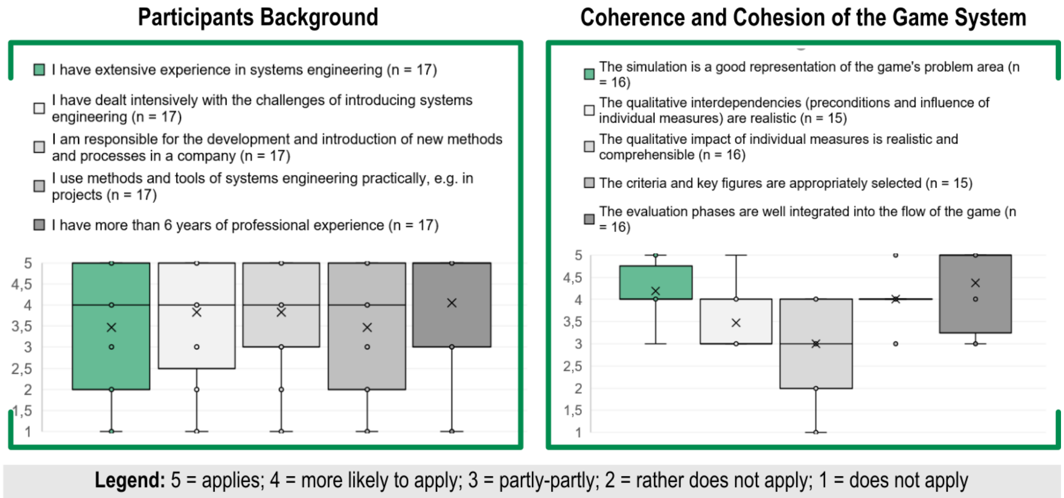

Figure 5. Excerpt from the results of the evaluation of the systemic simulation model

4.2. Evaluation of learning setting

In the second step, the evaluation of the SG relates to the learning setting and previous knowledge needed to ensure the defined learning outcomes, c.f. second research question in Section 1. Therefore, the participants were asked about the required knowledge and the purpose of the game using a questionnaire and nine statements. In Figure 6, an excerpt of the evaluation is presented. Most participants conclude that prior knowledge is needed to participate in the game. This knowledge can be gained from lectures at university or basic training in industry. However, it is not seen as a precondition that all participants have the same knowledge since questions and missing knowledge can be handled in the team, c.f. left hand side of Figure 6.

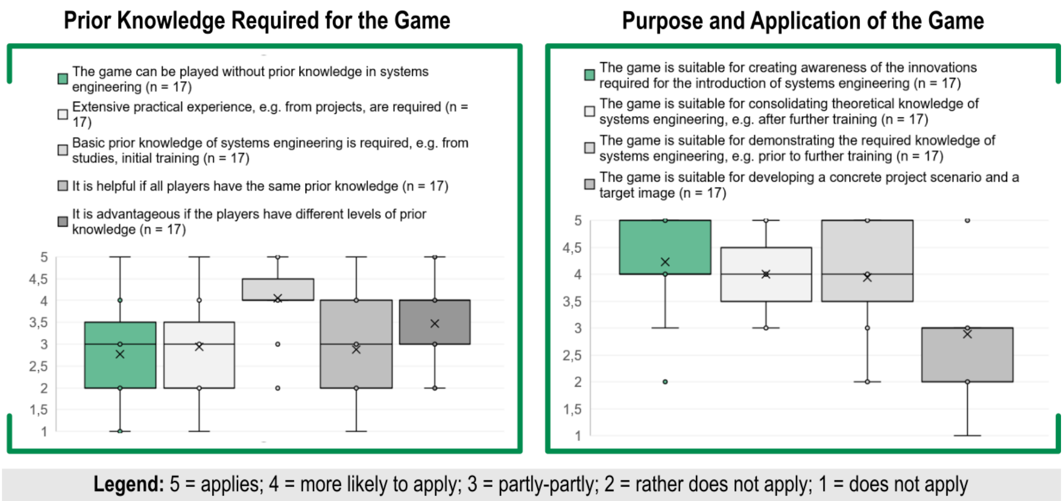

Figure 6. Excerpt from the results of the evaluation of the systemic learning setting

https://doi.org/10.1017/pds.2024.289 Published online by Cambridge University Press

Considering the application of the SG *creation of awareness*, *consolidation of theoretical knowledge* as well as *demonstration of required knowledge* are considered suitable. It can be concluded that the SG Systemic is suitable to demonstrate the required knowledge and deepen existing knowledge on SE in heterogeneous teams. At the same time, the SG is less suitable for developing a concrete project scenario.

5. Conclusion, discussion and further work

In this paper, the development and evaluation of the SG Systemic was presented. In the first step, the existing concepts and benefits of gamification in engineering education were discussed and the characteristics and development of the SG Systemic were presented. Based on a prototype it was investigated to what extent it is possible to simulate the manifold interdependencies that occur in real engineering projects and thus use them for gamification. Moreover, it was identified which previous knowledge is required to guarantee the defined learning outcomes. For this purpose, a first test session of the SG Systemic was conducted and evaluated with a group of experts from the SE-field and some people with less experience in SE. It can be concluded that the simulation model used in the SG is suitable to represent the complex relationships and dependencies observed between processes, methods, tools, and roles in reality. When selecting the criteria and KPIs, however, even more attention should be paid to representing and simulating the influences more realistic as well as using more consistent terms. With regard to the learning setting, it is important to note that at least basic SE knowledge is necessary to achieve the desired learning outcomes. For participants with little prior knowledge, the reading time within the gaming session is too high to achieve the desired learning effects. The initial evaluation of the SG Systemic indicates that, from the perspective of the participants the game is suitable for raising awareness required for the introduction of SE and for demonstrating and consolidating knowledge about SE. However, to be able to make a meaningful evaluation of the SG Systemic, it is necessary to increase the sample size and have more people testing the game and evaluating the results. In further research, it is planned to continuously develop the game and the simulation model (interactions, dependencies, influences, effects) after each implementation and to carry out further evaluations including different target groups like students and engineers from industry. Moreover, the effect of the SG on the learning outcomes will be investigated in more detail. The simulation model and the game mechanics will also be expanded and tested regarding Model-based Systems Engineering.

Acknowledgement

We gratefully thank all participants of the first SE Summit hosted at TU Clausthal in 2022 for giving their valuable feedback on the game prototype as well as participating in the survey. Moreover, we thank BeSu.Solutions GmbH for realizing the software and physical elements of the Simulation Game. Part of this research is performed within project RePASE - Reflective Process Development and Adaptation in Advanced Systems Engineering. This project is funded by the German Federal Ministry of Education and Research (BMBF) within the Program "Innovations for Tomorrow's Production, Services, and Work" (02J19B149) and managed by the Project Management Agency Karlsruhe (PTKA). The author is responsible for the contents of this publication.

References

Ammersdörfer, T., Inkermann, D., Müller, J., Mandel, C., Albers, A., Tekaat, J., Schierbaum, A., Anacker, H., Bitzer, M., Kleiner, S., Herrmann, J.P. and Krause, P. (2023), "Supporting Systems Engineering Activities by Arctifact-oriented Description and Selection of Methods", *Proceedings of the Design Society*, Vol. 3, pp. 3245–3254.

Baillie, C. and Fitzgerald, G. (2000), "Motivation and attrition in engineering students", in *European Journal of Engineering Education*, 25 (2), pp. 145–155.

Betts, B.W., Bal, J. and Betts, A.W. (2013), "Gamification as a tool for increasing the depth of student understanding using a collaborative e-learning environment", *International Journal of Continuing Engineering Education and Life-Long Learning*, Vol. 23 No. 3/4, pp. 213–228.

Bhatt, A.N., Acharya, S. and Chakrabarti, A. (2021), "Extended Taxonomy of Design and Innovation Games to Identfy Perspectives of Development and Evaluation", in *Proceedings of International Conference on Engineering Design (ICED21)*, Vol. 1, Gothenburg, Sweden, pp. 1547–1556.

Bhatt, A.N., Bhaumik, R., Moothedath Chandran, K. and Chakrabarti, A. (2019), "IISC DBox: A Game for Children to Learn Design Thinking", in *Proc. of the ASME 2019 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Vol. 3, Anaheim, California, USA.

Bhatt, A.N. and Chakrabarti, A. (2022), "Gamification of design thinking: a way to enhance effectiveness of learning", in *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 36, e29, Cambridge University Press, pp. 1–20.

Braghirolli, L.F., Ribeiro, J., Weise, A.D. and Pizzolato, M. (2016), "Benefits of educational games as an introductory activity in industrial engineering education", *Computers in Human Behavior*, Vol. 58, pp. 315–324.

Chang, Y., Aziz, E.-S., Zhang, Z., Zhang, M. and Esche, S.K. (2016), "Evaluation of a video game adaptation for mechanical engineering educational laboratories", in *Proc. of IEEE Frontiers in Education Conference (FIE)*, pp. 1–6.

Crawley, E.F., Malmqvist, J., Lucas, W.A. and Brodeur, D.R. (2011), "The CDIO syllabus v2.0. An updated statement of goals for engineering education", in *Proc. of 7th Int. CDIO Conference*, Copenhagen, Denmark.

Crooltall, D., Oxford, R. and Saunders, D. (1987), "Towards a reconceptualisation of simulation: from representation to reality", in *Simulation/Games for learning*, Vol. 17, pp. 147–171.

Deshpande, A.A. and Huang, S.H. (2011), "Simulation games in engineering education: A state-of-the-art review", in *Computer Applications in Engineering Education*, Vol. 19, pp. 399–410.

Deterding, S., Dixon, D., Khaled, R. and Nacke, L. (2011), "From game design elements to gamefulness", in *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments*, pp. 9–15.

Fernandes, J.M. and Sousa, S.M. (2010), "PlayScrum - A Card Game to Learn the Scrum Agile Method", in 2nd *International Conference on Games and Virtual Worlds for Serious Applications*, Braga, Portugal, pp. 52–59.

Hamari, J., Koivisto, J. and Sarsa, H. (2014), "Does Gamification Work? -- A Literature Review of Empirical Studies on Gamification", in *Proceedings of the 47th Hawaii International Conference on System Sciences*, Hawaii, USA, pp. 3025–3034.

Hartmann, A. and Gommer, L. (2021), "To play or not to play: on the motivational effects of games in engineering education", *European Journal of Engineering Education*, Vol. 46 No. 3, pp. 319–343.

Herrmann, C., Othmer, J., Mennenga, M., Nohr, R., Böhme, S. and Heinemann, T. (2011), "Business Game for Total Life Cycle Management", in *Proceedings of the 18th CIRP International*, pp. 531–536.

Hunicke, R., LeBlanc, M. and Zubek, R., "MDA: A Formal Approach to Game Design and Game Research", in *Proceedings of the AAAI Workshop 2004*.

Inkermann, D. (2021), "Shaping Method Ecosystems - Structured Implementation of Systems Engineering in Industrial Practice", *Proceedings of the Design Society*, Vol. 1, pp. 2641–2650.

Kharma, N., Caro, L. and Venkatesh, V. (2001), "MagicBlocks - A Construction Kit for Learning Digital Logic", *Computer Applications in Engineering Education*, No. 18, pp. 35–46.

Libe, C., Grenouillat, A., Lagoutte J., Jean, C. and Maranzana, N. (2020), "Creativity and innovation for children: presentation and first experiment of new (serious) game", in *DS 104 Proceedings of the 22nd International Conference on Engineering and Product Design Education, VIA Design*, VIA University Herning, Denmark.

Ma, Y., Vallet, F., Cluzel, F. and Yannou, B. (2020), "A Methodological Framework for Making the Transition From Traditional Innovation Teaching Towards Serious Games", in *Proceedings of the ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference - 2020, August 17-19, 2020, Virtual, Online*

Martin, J.N. (1994), "The PMTE Paradigm Exploring the Relationship Between Systems Engineering Process and Tools", paper presented at INCOSE International Symposium, August 10–12, San Jose, CA.

Mavromihales, M., Holmes, V. and Racasan, R. (2019), "Game-based learning in mechanical engineering education: Case study of games-based learning application in computer aided design assembly", *International Journal of Mechanical Engineering Education*, Vol. 47 No. 2, pp. 156–179.

Mitgutsch, K. and Alvarado, N. (2012), "Purposeful by design?: a serious game design assessment framework", in *Proceedings of the International Conference on the Foundations of Digital Games (FDG'12)*, ACM, New York, USA, pp. 121–128.

Vaibhav, A. and Gupta, P. (2014), "Gamification of MOOCs for increasing user engagement", in Garg, D. (Ed.), *IEEE International Conference on MOOC, Innovation and Technology in Education (MITE 2014), 19 – 20 December 2014, Patiala, India*, IEEE, Piscataway, NJ, pp. 290–295.

Wang, J., Yap, C.S. and Goh, K. (2017), "PBL in Engineering Education", in Guerra, A., Ulseth, R. and Kolmos, A. (Eds.), *PBL in Engineering Education*, SensePublishers, Rotterdam, pp. 71–88.

https://doi.org/10.1017/pds.2024.289 Published online by Cambridge University Press